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Comparison of mechanical properties of woven carbon reinforcements

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Abstract Important groups of laminates are long fibre reinforced composites. Carbon reinforced plastics are used in engineering and construction. They have low weight and very good mechanical properties. The properties of the laminate depend on the method of depositing the fibres in the reinforcement and processing the initial longitudinal textiles. Carbon fabrics are the most commonly used type of reinforcement for laminates. The weaving technology provides a variety of interlacing variations. New technology of production and modification of usually used tows bring significant improvement of their mechanical properties. The article described comparison mechanical properties of three woven fabric from carbon fibres according to produce technology original tows. In parallel, mathematical models of fabrics were created and the results were compared with the results of the experiment.

Introduction

The composite material is a combination of two or more materials with different properties. CFRPs are composites made of fibre-reinforced polymer matrix. The properties of the fibres in the composite material have a strong influence on their strength and stiffness. Carbon fibres offer a very good strength/stiffness to weight ratio [1]. Carbon fibre (CF) contains carbon atoms in various modifications. Crystals that are oriented in the direction of the fibre axis form the fibre. The crystal arrangement determines the strength of the fibre. The elemental carbon fibre has a diameter of 5-8µm, the carbon fibre density is 1.75g/m^3. PAN precursor carbon fibre industrial production began in the 1960s, production of carbon fibre from mesophase smol ten years later. CF are technical fibres with high strength and stiffness, but very low elongation, pitch fibres have very good flexural strength [2]. Carbon fibre longitudinal textiles are made by doubling elementary fibrils into tows (1, 3, 6, 12K) or rovings (24, 48, 50K). Carbon fabrics, multiaxial knitted fabrics and braided textiles are produced from carbon longitudinal textiles. Tows, fabrics, knitted textiles and 3D structures serve as a continuous dispersion of fibre reinforced plastics.

Tows 12K are made in two variants: round tow and flat tow format (referred to as WD). The flat tow is an ideal fibre to be used in applications where spreading is required (produce tapes, warp knitting and weaving textiles). Round tow is used, where spreading is not necessarily required (braiding and weaving technology) [3, 4]. The woven fabrics are made of two perpendicularly oriented systems of yarn, weft and warp yarns. The fabrics are produced on weaving loom by repeated weft insertion. The warp and weft material is usually the same, but the properties in the yarns direction are differ. Crossing of warp and weft yarns is called interlacing point. The layout of warp and weft interlacing points is crucial for weave of the

fabric and, above all, for its mechanical properties. For weaving is possible to use standard round tow, WD tow (flat tow format) and spread tow (SPF).
Carbon fabrics are quantify by the following parameters:
- number of elementary fibrils in one tow (number K),
- characteristics of the carbon fibre type used
- area weight,
- sett in warp and weft direction,
- weave [1].

Spread tow fabric (STF) is a tow layout into a wider and ultra-thin tape. Since 1990, there have been several patents that describe the procedure of spread tow production (using acoustic signal and vibration or pneumatic method). Spread tow is basis for produce woven structure. The SPF fabric is ultra-light and ultra-thin. On the market since 2014, Oxeon is the largest producer of this fabric under the trade name TeXtreme®. Two variants are produced; warp and weft orientation 0°/90 ° and warp and weft orientation ± 45° [3]. The tapes in the STF fabric are crimped, minimally deformed and allow maximum tensile load. The STF fabric can replace a conventional low basis weight fabric (made from 1K to 6K), or where radical weight reduction is required.

Experiment

Three carbon fabrics were selected for comparison of mechanical properties. Woven fabrics were produced from carbon tow 12K, tows were produced by different technology. Fabric No.1 was woven from standard tow 12K (round tow). Fabric No.2 was produced from flat tow (WD) – fibres in tow 12K were arranged to 5mm tow width. Fabric No.3 was produced from spread tow (SPF) - fibres in tow 12K were arranged using special spread technology to 15mm tow width. The fabrics were defined by the following parameters: warp and weft material, area weight, square sett and weave. Look of carbon fabrics shows Fig. 1.

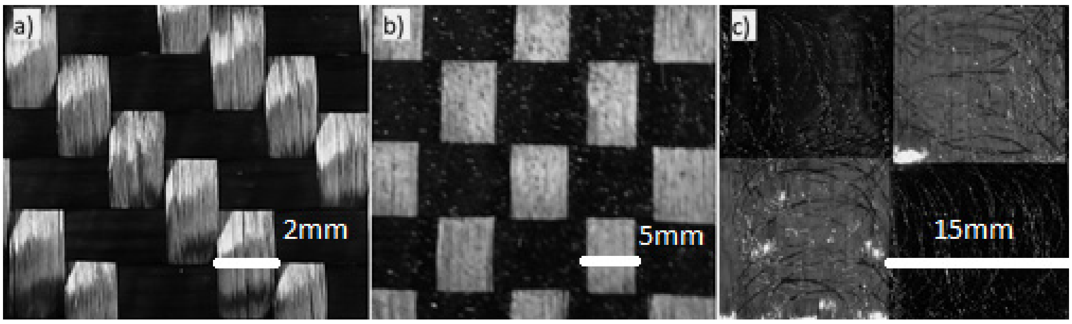


Fig. 1: Woven fabric; a) standard tow, b) flat tow, c) spread tow

Six specimens were prepared in the warp direction and in weft direction from each fabric. Specimens were prepared according to ČSN EN ISO 13934-1. Dimensions of specimens were: length 200mm, width 50 mm. Special attentions was given to the selvedge of specimens. The standard prescribes the removal of yarns of 5mm width. Specimens were weighed, fineness of carbon tows – 12K (800tex) was defined. Sett in warp and weft direction and weave were defined according the Standard. The basic fabrics parameters are showed in Table 1.

Table 1: Woven fabric parameters

Fabric	Weave	Weight [gm^{-2}]	Sett wa/we
1 (Fig.1a)	Twill 12K	600	440/440
2 (Fig.1b)	Plain 12K	193	120/120
3 (Fig.1c)	Plain 12K	160	67/67

Thickness of specimens was measured using thickness gauge (SDL M 034/1). Tensile strength test was realized on strength testing machine (Tiratest T2400), speed of test was 2mm/min. Tensile curves, values of maximum break force (F_{max}), maximal strength (R_{max}) and tensile strength modulus (E) were results of test.

Mathematical models

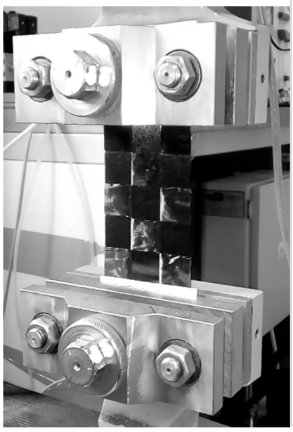
The 2D shell model of carbon fabrics was created to simulate the tensile test in Solidworks. The test sample model was 100 x 50 mm in size. The created model was imported into Ansys. The thickness of the simulated samples varied according to the measured values. The FEM network was introduced into the model. The mash was defined by face mapping with a combination of 1 mm Face Sizing. The mash model created contained 4989 nodes and 4844 elements. Fixing boundary conditions were inserted at the bottom of the model. These boundary conditions prevented the rotation and movement of the sample to all sides. The force boundary condition was inserted into the top of the model [5, 6]. The condition value was changed depending on the properties of specimens. The values used for mathematical models are summarized in Table 1 and Table 2.

Results

Tensile strength test (Fig. 2) was realized for prepared fabrics specimens in warp and weft directions. Table 2 presents the fabric parameters and maximum break force. Tensile curves, values of maximum break force (F_{max}), maximal strength (R_{max}) and tensile strength modulus (E) were results of test. Graph of R_{max} values shows Fig. 3.

Table 2: Results of measurements

Fabric	Sett [m^{-1}]	Thickness [mm]	Number of filaments [m^{-1}]	F_{max} [N]
1 warp	440	0.83	5280K	3955
1 weft	440	0.83	5280K	3448
2 warp	120	0.35	1440K	5206
2 weft	120	0.35	1440K	4552
3 warp	67	0.19	804K	5348
3 weft	67	0.19	804K	5317



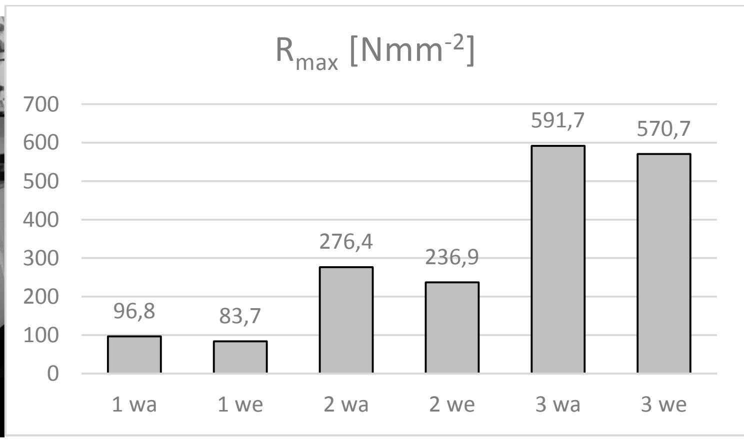


Fig. 2: Measurement of fabric

Fig. 3: Graph of maximal strength

The results summarized in Table 2 show significant differences between the thickness of the fabrics, the numbers of elementary fibrils and the strength value R_{max}. The properties of elementary fibrils are comparable, fineness of tow is the same but design and produce technologies of tows are different. The test results indicate that the effective use of the mechanical properties (maximal strength R_{max}) of carbon fibres is relatively low for standard fabrics. Flat tows ensure a higher percentage of fibre utilization. The maximum strength R_{max} of the fabric is three times higher. Spread tow treatment has maximized the mechanical properties; the maximal strength R_{max} of fabric is six time higher. The differences between warp and weft direction is minimal for fabric made of spread tows. Figure 4 shows damage of fibres after test.

Fig. 4: Damage of elementary fibres after test; a) standard tow, b) flat tow, c) spread tow

The simulation results showed that the maximum deflection and stress values are directly dependent on value of force and thickness of the fabric. The results of the mathematical model summarizes Table 3.

Table 3: Results of mathematical model

Fabrics	Deformation [mm]	Stress von-Mises [MPa]
1 warp	2.31	376
1 weft	2.10	341
2 warp	3.14	996
2 weft	2.87	847
3 warp	2.80	2020
3 weft	2.95	2169

Figure 5 shows a comparison of the mathematical model of size and stress distribution in the test specimens in the warp direction during tensile strength test.

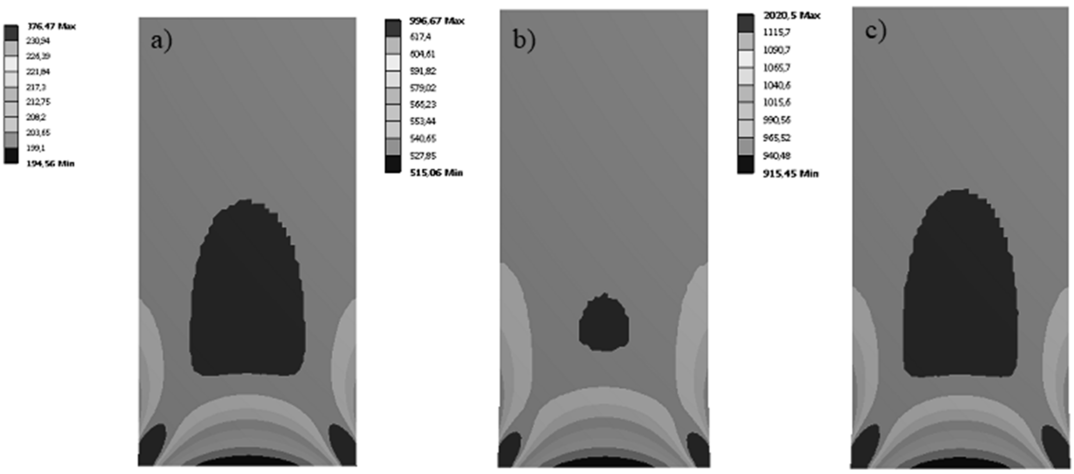


Fig. 5: Stress (von Mises) in a warp direction in a maximum time of 1s for fabrics;
a) standard tow, b) flat tow, c) spread tow

Conclusions

The measurement showed that the spread tow treatment significantly affects the mechanical properties of the woven carbon reinforcement. The spread tow fabric contains a significantly lower number of elementary fibrils; but its mechanical properties are significantly higher than those of standard carbon fabric.

A 2D shell model was created into which mechanical properties of individual materials and their thickness was imported. Comparing the results of the tests and calculations of the mathematical model is to show the degree of agreement. The graph of Fig. 6 shows the comparison of mathematical model maximal strength von Mises and measured values of carbon fabric strength. Based on comparison, design elements with mechanical properties for specific applications will be proposed.

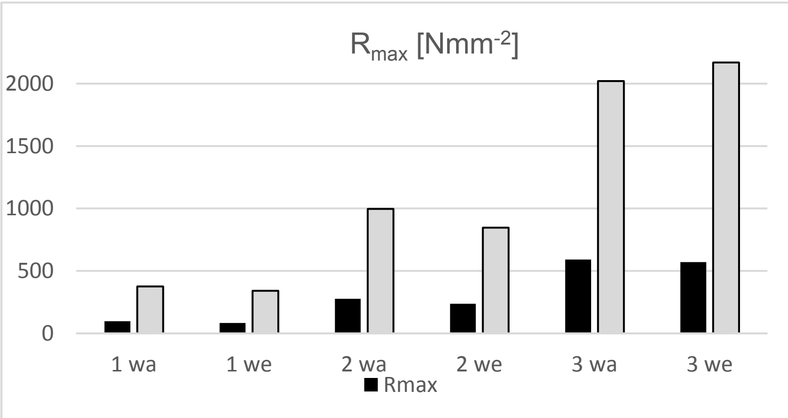


Fig. 6: Comparison of measured values of R_{max} and simulated values of R_{max} (von Mises)

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